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RECOMMENDED VEHICLE CONCEPTS FOR WATERJET PROPELLED HIGH-PERFORMANCE VEHICLES

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A rapid method is developed for providing first order estimates of the smooth water powering and weight characteristics of SES, hydrofoil, and planing craft concepts employing waterjet propulsors. A computer program utilizing this method and applicable to SES concepts is included.

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TABLE OF CONTENTS

NOTATION

b	Cushion beam, feet
C_{DA}	Appendage drag coefficient
C_f	Skin friction coefficient
D	Total vehicle drag, lbs
D_a	Appendage drag, lbs
D_e	External aerodynamic drag, lbs
D_s	Dry stores duration, days
D_{SK}	Seal (or ski) drag, lbs
$D_{s,a}$	Sidewall frictional drag, lbs
$D_{s,v}$	Additional (external) sidewall frictional drag, lbs
$D_{s,w}$	Sidewall wavemaking drag, lbs
D_W	Wavemaking drag, lbs
F_ℓ	Froude number based on ℓ
f_ℓ	Wavemaking drag parameter
g	Acceleration of gravity, ft/sec^2
h_a	Fully wetted sidewall depth, feet
K_d	Waterjet system loss coefficient (includes internal and elevation losses plus an equivalent loss to account for the additive inlet induced external drag)
L/D	Lift-drag ratio
ℓ	Cushion length, feet
N_c	Number of accommodations
P_o	Design cushion pressure, psf
P	Shaft horsepower delivered to the pump, h.p.
P_e	Power required at V_{K_e}. h.p.
P_{en}	Power required per engine at V_{K_e}, h.p.
P_L	Lift horsepower required, h.p.

P_{MC} Available maximum continuous shaft horsepower, h.p.

P_{MI} Available maximum intermittent shaft horsepower, h.p.

P_p Propulsive horsepower required, h.p.

P_{SH} 1.15 times power required at $V_{K_{max}}$, h.p.

P_{sf} Design foil loading, psf

q_a Air dynamic pressure, psf

q_w Water dynamic pressure, psf

R Vehicle range, miles

r Wavemaking resistance coefficient

S Cushion planform area, ft^2

sfc Specific fuel consumption, lb/h.p.-hr

V_K Vehicle speed, knots

V_{K_e} Vehicle endurance speed, knots

V_{K_d} Vehicle design speed, knots

V_{K_H} Primary hump speed, knots

$V_{K_{max}}$ Maximum vehicle speed, smooth water, knots

V_{K_t} Take-off speed, knots

W Vehicle gross weight, lbs

W_{aux} Auxiliary systems and outfit and furnishings weight, tons

W_{ces} Complement, personal effects, and stores weight, tons

W_e Electric system weight, tons

W_f Fuel weight, tons

W_m Propulsion system weight, tons

$W_{P/L}$ Payload weight, tons

W_s Hull structure weight, tons

W_{s_1} Lift systems weight, tons

α Ratio of V_{K_d} to $V_{K_{max}}$

β Ratio of V_{K_t} to $V_{K_{max}}$

γ Lift horsepower-to-propulsive horsepower ratio

η Overall propulsive coefficient

η_p Pump efficiency

$\eta_{p_{max}}$ Maximum pump efficiency

ρ Fluid density, lb sec^2/ft^4

Δ Vehicle gross weight, tons

ADMINISTRATIVE INFORMATION

This work was requested by the Propulsion and Auxiliary Systems Department and was funded under Task Area SF 43 421 012, Task 17229, Work Unit 1-2721-144-40.

INTRODUCTION

The project objective is to recommend "Reference Craft" for use in an exploratory development program of waterjet propulsion systems. The vehicle concepts recommended in this report are limited to 200 tons. However, other vehicle sizes may readily be examined by utilizing the method presented herein.

A rapid method is developed for estimating the overall propulsive coefficient and the drag of a vehicle concept over its operating speed range. Thus, an estimate of the shaft horsepower required as a function of speed may be obtained. Preliminary weight estimating relationships are also included so that predictions of fuel weight and payload weight may be made. A computer program utilizing this method and applicable to SES vehicle concepts is contained in Appendix A.

Some of the equations used in the method are presented without derivation. Future reports will cover the development of these relationships.

THE OVERALL PROPULSIVE COEFFICIENT FOR WATERJET PROPELLED VEHICLES

The overall propulsive coefficient η is defined by,

$$\eta = \frac{D(1.6878V_K)}{550\ P}$$

where D is the total vehicle drag, exclusive of that drag induced by the inlet, in pounds, V_K is the speed of the vehicle in knots, and P is the shaft horsepower delivered to the pump at the vehicle speed V_K. For purposes herein we assume a transmission efficiency of unity.

For parametric analysis of waterjet propelled high performance vehicle concepts operating in a patrol type mission, i.e., cruising at some specified speed (e.g., 20 knots) and having a specified maximum (dash) speed (e.g., 75 knots), it is necessary to be able to estimate the powering requirements at the specified cruising speed so that fuel weight requirements corresponding to the specified cruising range may be determined. When the desired cruising speed coincides with hull-borne or pre-hump operation, it will be assumed that the vehicle concept has a hull-borne waterjet propulsion system, in addition to the primary (high speed) system, which can be characterized by supposing that a small hull-borne inlet/pump/engine system is included as part of the propulsion system. The equation (to be developed) for η will, in addition to providing an estimate of η for the primary waterjet system, enable characterization of this "secondary" propulsion system efficiency over the hull-borne speed range.

An expression for the overall propulsive coefficient, as given in reference (1) [Equation 6], is

$$\eta/\eta_p = 2[(1 - k - \frac{2gh}{V^2} + \frac{2gH}{V^2})^{1/2} - 1]V^2/(2gH) \qquad [1]$$

where

η_p is the pump efficiency

k is the ratio of total inlet and internal energy losses (exclusive of elevation changes) to the vehicle velocity head ($V^2/2g$)

h is the difference in elevation between the nozzle exit and the water surface, ft

H is the head produced by the pump, ft-lb/lb

g is the acceleration due to gravity, ft/sec^2

V is the forward speed of the vehicle, ft/sec

As no attempt is made herein to estimate the inlet induced external drag, we account for this additive drag by penalizing the overall propulsive coefficient. This is done by replacing $K = k + \frac{2gh}{V^2}$ (the magnitude of which, in reference (1), is taken to be fixed for a fixed geometry) by a waterjet system loss coefficient K_d, which includes internal (inlet plus duct) and elevation losses plus an equivalent loss to account for the additive inlet induced external drag. Equation [1] then becomes

$$\eta/\eta_p = [(1 - K_d + \frac{2gH}{V^2})^{1/2} - 1]V^2/(gH) \qquad [2]$$

As pointed out in reference (1), this equation has a maximum value for a given value of K_d so that there is an optimum value for H. This is found, as in reference (1), by differentiating Equation [2] with respect to $H^* = \frac{2gH}{V^2}$ and solving for H. The result is

$$H_{opt} = \frac{V_d^2}{g}[K_d + \sqrt{K_d}]$$

where V_d denotes the particular value of V for which H is optimum. Reference (1) suggests that if the magnitudes of pump head and flow rate at cruise (design) speed are maintained at take-off speed, then the additional thrust required at take-off may be produced. Following this reasoning, we assume that the magnitude of H is a constant $H = H_{opt}$, i.e.,

$$H = \frac{V_d^2}{g}[K_d + \sqrt{K_d}] \qquad \text{if } 0 < V \leq V_d$$

Replacing H in Equation [2] by this relationship and setting $V_d = \alpha V_{max}$, $0 < \alpha \leq 1$, gives

$$\eta/\eta_p = [(1 - K_d + \frac{2(K_d + \sqrt{K_d})}{(V_K/\alpha V_{K_{max}})^2})^{1/2} - 1]\frac{(V_K/\alpha V_{K_{max}})^2}{(K_d + \sqrt{K_d})} \qquad [3]$$

$$\text{if } 0 < V_K \leq V_{K_d}$$

where the vehicle speeds are now given in units of knots.

An estimate for the pump efficiency η_p is needed which has a specified maximum $\eta_p = \eta_{p_{max}}$ when $V_K = V_{K_d}$. Moreover, the effect of K_d should be included since the magnitude of the total head above vapor pressure at the impeller, H_{SV} (referred to as the net positive suction head), is given by

$$H_{SV} = (1 - k) \frac{V^2}{2g} + h_{SV} - h_{pi}$$

where h_{SV} is the difference between atmospheric and vapor pressure expressed as a head in feet of water and h_{pi} is the elevation of the pump inlet above the free water surface (if the pump inlet is below the free water surface, then h_{pi} is a negative quantity). Referring to the equation for H_{SV} it is seen that, for a fixed vehicle speed, the magnitude of H_{SV} increases as k (or K_d) decreases with a corresponding increase in the pump specific speed for a given pump.

Test results for the XR1-B and calculations were used to determine the variation of pump efficiency with vehicle speed. This variation can be characterized by a slowly increasing function of vehicle speed which reaches a maximum value at design speed. Such a function is

$$\eta_p = \eta_{p_{max}} \left[1 - C_1 \left(1 - \frac{V_k}{V_{K_d}}\right)^2\right]$$

where $\eta_{p_{max}}$ is the maximum pump efficiency and C_1 is assumed to be a function of K_d.

We assume that the above functional relationship between pump efficiency and vehicle speed is generally true and that, as discussed previously, the propulsion system losses (as reflected by K_d) slightly affect the pump efficiency. To estimate this effect, the ratio

$\sqrt{K_d}/(1 + \sqrt{K_d})$ is assumed for the constant C_1 as it provides small variations in the magnitude of η_p for a considerable range of K_d values. The validity of this assumption will have to be verified when more experience is gained in the application of waterjet propulsion systems to high-speed vehicles. The equation selected to estimate the pump efficiency is

$$\eta_p = \eta_{p_{max}} [1 - \frac{\sqrt{K_d}}{1 + \sqrt{K_d}} (1 - \frac{V_K}{\alpha V_{K_{max}}})^2] \qquad \text{if } 0 < V_K \leq V_{K_d} \quad . \qquad [4]$$

Combining Equations [3] and [4] gives an estimate of the overall propulsive coefficient η over the speed regime $(0 < V_K \leq V_{K_{max}})$ for a vehicle concept with a specified loss level (K_d) and a specified maximum pump efficiency, $\eta_{p_{max}}$, i.e.,

$$\eta = \frac{\eta}{\eta_p} \cdot \eta_p \qquad \text{if } 0 < V_K \leq V_{K_d} \qquad [5]$$

For high-speed operation, the design speed $V_{K_d} = \alpha V_{K_{max}}$, should be set equal to $V_{K_{max}}$, i.e., $\alpha = 1$. If a secondary propulsion system is assumed for purposes of cruise range specification at low speed, then a second set of values, α, K_d, and $\eta_{p_{max}}$, should be selected and used in Equation [5] to determine the η for this propulsion system.

In using this method for estimating the overall propulsive coefficient of waterjet propelled vehicle concepts, the waterjet system loss coefficient K_d may be treated as a parameter.

In this case the following tentative range of magnitudes for K_d are recommended for preliminary performance estimates:

Waterjet System	Recommended K_d Values
Flush or semi-flush inlet (hull)	.4 - .5
Hydrofoil strut/pod ram inlet	.65 - .75
Semi-flush/ram inlet (short strut)	.5 - .65

SES DRAG AND POWER ESTIMATES

The drag estimates for SES (rigid sidewall ACV's) are obtained by a summation of component drag relationships based essentially on the procedure given in references (2) and (3). As an approximation, it is assumed that the SES is fully cushion supported (i.e., $W = p_o S$, where W is the gross weight in lbs, p_o is the design cushion pressure in psf, and S is the cushion planform area in ft^2), that the cushion planform is rectangular, that the sidewall length is equal to the cushion length (ℓ), and that the daylight clearance is zero. Consistent with the latter assumption, the ram (or momentum) drag is taken to be zero.

The equations used to predict the component drag to weight ratios are as follows:

Wavemaking drag, D_W: From reference (2), this component is given by

$$\frac{D_W}{W} = \frac{4}{\rho g} \cdot \frac{p_o}{\ell} \cdot f_\ell \qquad [6]$$

where p_o/ℓ is the design pressure to cushion length ratio and f_ℓ is the wave drag parameter. A closed form analytical expression for f_ℓ has been developed, assuming a uniform pressure distribution acting over a rectangular region. It is

$$f_\ell(F_\ell,\lambda)=\begin{cases} \dfrac{16\lambda}{\pi F_{\ell_H}^{\;4}}\cdot\dfrac{F_\ell^{\;2}}{(1+1.6\lambda^{1/4})^2}\left\{3-\gamma+\ln\dfrac{(1+1.6\lambda^{1/4})^2F_{\ell_H}^2}{16\lambda}\right\} & \text{if } 0\le F_\ell\le\frac{1}{2}F_{\ell_H} \\ e^{-\sqrt{\lambda}}\,F_\ell^{1/4}\sin^2\left[\dfrac{\pi F_{\ell_H}^{\;2}}{2F_\ell^{\;2}}\right]+\dfrac{\lambda}{\pi}\cdot\dfrac{1}{(F_\ell+\frac{4}{5}\lambda^{1/4}F_{\ell_H})^2}\left\{3-\gamma+\ln\dfrac{\left(F_\ell+\frac{4}{5}\lambda^{1/4}F_{\ell_H}\right)^2}{4\lambda}\right\} & \text{if } \frac{1}{2}F_{\ell_H}\le F_\ell\le\frac{4}{5}\lambda^{1/4}F_{\ell_H} \\ e^{-\sqrt{\lambda}}F_\ell^{\;1/4}\sin^2\left[\dfrac{\pi F_{\ell_H}^{\;2}}{2F_\ell^{\;2}}\right]+\dfrac{\lambda}{4\pi}\cdot\dfrac{1}{F_\ell^{\;2}}\left\{3-\gamma+\ln\left(\dfrac{F_\ell^{\;2}}{\lambda}\right)\right\} & \text{if } \frac{4}{5}\lambda^{1/4}F_{\ell_H}\le F_\ell \end{cases}$$

where

$\lambda = \ell/b$ is the length-beam ratio of the rectangular planform

$\gamma = .577...$ is Euler's constant

$F_\ell = V/\sqrt{g\ell}$ is the Froude number

$F_{\ell H} = V_H/\sqrt{g\ell}$ is the primary hump Froude number, which is estimated by $F_{\ell_H} = \sqrt{\frac{1}{\pi} + .01745\,\lambda^2}$

Sidewall frictional drag, $D_{s,a}$:

For 2 sidewalls, this component is given in reference (2) by

$$\frac{D_{s,a}}{W} = \frac{4}{W}\cdot C_f\cdot q_W\cdot \ell\cdot h_a \qquad [7]$$

where C_f is the skin friction coefficient, q_w is the water dynamic pressure $(2.835V_K^2)$, and h_a is the fully wetted sidewall depth. The following estimate for h_a is used.

$$h_a=\left\{\begin{array}{ll} \dfrac{P_o}{\rho g}\left[1-.8\left(\dfrac{F_\ell}{F_{\ell_H}}\right)^2\right] & \text{if } 0\le F_\ell\le F_{\ell_H} \\ .2\,\dfrac{P_o}{\rho g} & \text{if } F_{\ell_H}\le F_\ell\le F_{\ell_{max}} \end{array}\right\};\ \text{ft.}$$

Additional (external) sidewall frictional drag, $D_{s,v}$: According to reference (2), this component is given as

$$\frac{D_{s,v}}{W} = C_f \cdot \frac{\ell}{b} \cdot \frac{q_w}{P_o} \cdot \frac{D_W}{W} \qquad [8]$$

Sidewall wavemaking drag, $D_{s,w}$: This component, as given in reference (3), is

$$\frac{D_{s,w}}{W} = \frac{r}{W} \cdot \frac{8\rho g}{\pi} \cdot \frac{B^2H^2}{L} \qquad [9]$$

Values of the wavemaking resistance coefficient, r, for a full form, having B/L = .0265, B/H = .183, and L/H = 7, were taken from reference (4). For Froude numbers between 0 and 1.80, the magnitude of r is computed by interpolation of these stored values. For larger Froude numbers, the following approximation is used.

$$r = 6.125 \cdot \frac{1}{F_\ell^{\,2}} \cdot \ln F_\ell \qquad \text{if } 1.80 \leq F_\ell$$

The assumption is also made that $H = h_a$.

External aerodynamic drag, D_e: As given in reference (2), this component is

$$\frac{D_e}{W} = \frac{.2}{\ell/b} \cdot \frac{q_a}{P_o} \qquad [10]$$

where q_a is the air dynamic pressure ($.00339V_K^2$). Here we have assumed the estimate of $.2/(\ell/b)$ for the aerodynamic drag coefficient as given in reference (5).

Seal (or ski) drag, D_{SK}: For this component, a flat planing surface is assumed. The average bottom planing speed is taken to be equal to the vehicle speed and the ski width is assumed equal to b. The drag for two seals is then

$$D_{SK} = 2 \cdot \frac{1}{2}\rho V^2 C_{f_{\ell'}} \cdot \ell' b = 2q_w C_{f_{\ell'}} \ell' b$$

where $C_{f_{\ell'}}$ is the flat plate skin friction coefficient and ℓ' is the chord length of the ski. Assuming $\ell' = .025\ell$ and $C_{f_{\ell'}} = 2C_f$ gives

$$\frac{D_{SK}}{W} = .1 \cdot C_f \cdot \frac{q_w}{P_o} \quad . \tag{11}$$

Appendage drag, D_a: Reference (6) gives an estimate for the drag coefficient of parabolic cross section appendages. If the values .01 and .1 are assumed for appendage area to cushion area ratio and thickness to chord ratio, respectively, then the drag coefficient given therein becomes

$$C_{DA} = .0000393 + .02C_f$$

The appendage drag is then taken to be

$$\frac{D_a}{W} = \frac{C_{DA} q_w}{P_o} \tag{12}$$

The total drag to weight ratio (D/W) is obtained as the sum of Equations [6] through [12], i.e.,

$$\frac{D}{W} = \frac{D_W}{W} + \frac{D_{s,a}}{W} + \frac{D_{s,v}}{W} + \frac{D_{s,w}}{W} + \frac{D_e}{W} + \frac{D_{SK}}{W} + \frac{D_a}{W} \tag{13}$$

from which we obtain the propulsive horsepower to weight ratio as,

$$\frac{P_p}{W} = \frac{D}{W} \cdot \frac{V_K}{326\eta} \tag{14}$$

where V_K is the vehicle speed in knots and η is the overall propulsive coefficient.

It is assumed that the lift horsepower required (P_L) is proportional to propulsive power required, i.e.

$$\frac{P_L}{W} = \gamma \cdot \frac{P_p}{W} \qquad [15]$$

The smooth water shaft horsepower required is now given as

$$P = \left(\frac{P_p}{W} + \frac{P_L}{W}\right) \cdot W \qquad [16]$$

where W is the gross weight of the SES in pounds.

HYDROFOIL DRAG AND POWER ESTIMATES

Smooth water drag estimates for hydrofoil vehicles are based on empirical relationships developed for estimating vehicle lift-drag ratios, L/D,over the vehicle's speed regime for hydrofoils having either subcavitating or supercavitating lift systems.

For hydrofoil vehicles having subcavitating lift systems, the L/D curve (as a function of vehicle speed) decreases rapidly with increasing speed in the hullborne condition until take-off (where L/D is a minimum) after which the L/D curve increases to a maximum value (depending on cavitation conditions) and then decreases again as cavitation becomes more severe. To include the effect of various take-off speeds on L/D, the take-off speed, V_{K_t} is defined by setting $V_{K_t} = \beta V_{K_{max}}$, $0 < \beta < 1$.

To provide the variation of L/D over the whole vehicle speed range, the following variation for subcavitating L/D's is selected

$$
L/D = \begin{cases} \dfrac{550}{V_{K_{max}}} \cdot \beta^{2.5} \cdot \dfrac{1}{(V_K/V_{K_{max}})^2} & \text{if } 0 < V_K < V_{K_t} \\[2ex] \dfrac{550}{V_{K_{max}}} \cdot \dfrac{1}{\beta^{1.5}} \cdot \left(\dfrac{V_K}{V_{K_{max}}}\right)^2 & \text{if } V_{K_t} \leq V_K < \sqrt{\beta}\, V_{K_{max}} \\[2ex] \dfrac{550}{V_{K_{max}}} \cdot \dfrac{1}{(V_K/V_{K_{max}})} & \text{if } \sqrt{\beta}\, V_{K_{max}} \leq V_K \leq V_{K_{max}} \end{cases} \qquad [17]
$$

where the empirical constant is selected so that the L/D at 50 knots is 11. This is based on an average of L/D's attained by existing hydrofoils.

The variation of L/D with vehicle speed for hydrofoil vehicles with supercavitating lift systems is assumed to be similar to the variation of L/D with vehicle speed for subcavitating lift systems throughout the hullborne speed range. After reaching a minimum at take-off, the L/D is assumed to slowly increase throughout the foilborne speed range. The following variation of L/D with vehicle speed reflects the above assumptions.

$$
L/D = \begin{cases} \dfrac{550}{V_{K_{max}}} \cdot \beta^{2.5} \cdot \dfrac{1}{(V_K/V_{K_{max}})^2} & \text{if } o < V_K < V_{K_t} \\[2ex] \dfrac{550}{V_{K_{max}}} \cdot (V_K/V_{K_{max}})^{1/2} & \text{if } V_{K_t} \leq V_K \leq V_{K_{max}} \end{cases} \qquad [18]
$$

The same empirical constant is selected as it gives L/D's of 7.33 and 5.5 at 75 and 100 knots, respectively. These magnitudes are considered to be attainable with careful design in the near future.

The smooth water shaft horsepower delivered to the pump is given as,

$$
P = \frac{6.87\,\Delta\, V_K}{\eta(L/D)} \qquad [19]
$$

where $\Delta = W/2240$ is the gross weight of the hydrofoil in tons.

PLANING CRAFT DRAG AND POWER ESTIMATES

The smooth water drag estimates for planing craft are based on Series 62 data (reference (7)). For the planing craft considered herein, Figure 12(a) of reference (7) was used to determine the resistance to weight ratios D/W, i.e., a length to beam ratio of 5.5 was selected and the 8% LCG curves were used.

The shaft horsepower required is given by

$$P = \frac{D}{W} \cdot \frac{W\, V_K}{326\, \eta} \qquad [20]$$

WEIGHT ESTIMATES, ALL VEHICLES

In order to obtain first order payload weight estimates, it is necessary to estimate the component weights of the selected vehicle concepts. Ordinarily, one would specify payload weight and estimate the gross weight; however, in this case an iterative procedure is required to solve the weight equation for gross weight. By specifying a gross weight (Δ) the payload weight may be calculated explicitly.

The following relationships were selected for use in estimating component weights.

Hull Structure: The hull structural weight group W_s includes the main body and hull structure, superstructure, and machinery foundations. A minimum structural weight envelope given in reference (8) was selected for hydrofoils based on the best currently available material technology and construction techniques. This was increased by approximately 28% for planing craft based on a recent planing craft design. A weight estimate for SES, as a function of ℓ/b and P_c/ℓ, was developed based on the variations presented in both references (6) and (9).

The hull structural weights are given by

$$W_S = \begin{cases} .15\,\Delta + .25\,\Delta^{.7} & ;\ \text{HYDROFOILS} \\ .19\,\Delta + .32\,\Delta^{.7} & ;\ \text{PLANING CRAFT} \\ \frac{\Delta}{\sqrt{P_o/\ell}}\left[\frac{1}{\Delta^{1/3}} + \frac{.3}{(\ell/b)^{1/3}}\right] & ;\ \text{SES} \end{cases} \quad ;\ \text{TONS} \qquad [21]$$

Lift Systems: The lift systems weight group W_{s_1}, includes the foil system weight in the case of hydrofoils and the seal system weight in the case of SES's. The equation selected for estimating the weight of hydrofoil lift systems, whose form is taken from reference (6), is assumed to depend on gross weight and the design foil loading P_{sf} in lbs/ft^2. The lift system weight for SES's is taken proportional to gross weight.

$$W_{s_1} = \begin{cases} \frac{84\Delta}{P_{sf}} + \frac{.275}{\sqrt{P_{sf}}}\Delta^{3/2} & ;\ \text{HYDROFOILS} \\ .05\Delta;\ \text{SES} & \\ 0;\ \text{PLANING CRAFT} & \end{cases} ;\ \text{TONS} \qquad [22]$$

The magnitude selected for P_{sf} should not exceed 2100 PSF as the resulting weight estimate might be too low.

Propulsion System: This weight group includes the prime movers and the transmission and propulsor systems. Based on available data for two recent high-performance vehicles, SES 100A and PHM, a specific weight (lbs of propulsion system/maximum intermittent shaft horsepower) of 3 lb/h.p. is selected to provide an estimate of marine gas turbine/waterjet propulsor/light weight transmission propulsion systems. If a secondary propulsion system is required, then an additional .5 lb/h.p. is assumed. This gives

$$W_m = \begin{cases} .001339\ P_{MI};\ \text{if 1 propulsion system} \\ .001562\ P_{MI};\ \text{if 2 propulsion systems} \end{cases} ;\ \text{TONS} \qquad [23]$$

where P_{MI} is the available maximum intermittent shaft horsepower (80°F). The magnitude of P_{MI} is selected such that it exceeds the larger of either 1.15 times the power required at $V_{K_{max}}$, ($P_{SH} = 1.15P(V_{K_{max}})$), or the power required at hump, $P(V_{KH})$ or take-off, $P(V_{K_t})$. If existing (or planned) gas turbines are not considered, then the estimate

$$P_{MI} = MAX[P_{SH}, P(V_{KH})]$$

may be used.

Electric System: This group is a small percentage of gross weight, and for our purposes, the following equation is selected based on an approximate average of the SES 100A and PGH-2.

$$W_e = .03\Delta;\ \text{TONS} \qquad [24]$$

Auxiliary Systems and Outfit and Furnishings: This group comprises a larger percentage of gross weight than the electric plant, however, it is still comparatively small relative to the previous groups. The weight of this group is taken to be 10 percent of the gross weight on the basis of the SES 100A and a recent planing craft design, i.e.,

$$W_{aux} = .1\Delta;\ \text{TONS} \qquad [25]$$

Complement, Personal Effects, and Stores: This group consists of the accommodations dependent weight items, some of which may be a function of duration at sea measured in terms of dry stores duration in days. The complement and personal effects weight is estimated by assuming 225 lbs/man. The stores weight per man is assumed to be proportional to the dry stores duration. Based on the PGH-2 and a recent planing craft design, we obtain the following equation

$$W_{ces} = .1N_c + .015N_cD_s;\ \text{TONS}, \qquad [26]$$

where N_c is the number of accommodations and D_s is the dry stores duration in days.

<u>Fuel</u>: This weight group includes the fuel required to meet the range requirements specified for the mission. The fuel weight equation used is

$$W_f = \Delta(1 - e^{-\frac{(sfc)RP_e}{2240\Delta V_{K_e}}});\ \text{TONS}, \qquad [27]$$

where sfc is the specific fuel consumption in lbs/h.p.-hr. and R is the specified range in miles. Estimates for sfc are made by using an equation developed by H. D. Marron, Naval Ship Research and Development Center, NSRDC, Annapolis, for sfc's corresponding to maximum continuous power ratings of second generation gas turbines; however, as an approximation we assume it valid for the power per engine P_{en} where P_{en} is the estimated power required at V_{K_e}, P_e, divided by the number of engines installed. The equation is sfc = $1.9\ P_{en}^{-.15}$. For hydrofoil and SES concepts where hullborne range is specified, an sfc of .4 is assumed to reflect a small diesel installation.

The payload $W_{P/L}$ is defined to consist of those items comprising NAVSHIPS weight groups 4 and 7 (communications and control and armament, respectively) all variable load payload and margins. The payload weight, given in terms of Equations [21] through [27] via the weight equation, is

$$W_{P/L} = \Delta - (W_s + W_{s_1} + W_m + W_e + W_{aux} + W_{ces} + W_f);\ \text{TONS.} \qquad [28]$$

APPLICATION OF THE METHOD OF ESTIMATING THE PRIMARY CHARACTERISTICS OF SES'S, HYDROFOILS, AND PLANING CRAFT

The equations presented for estimating the powering characteristics and weight characteristics of SES, hydrofoils, and planing craft may now be solved provided certain design parameters are known. In this section these parameters are discussed and defined.

Design Specifications Common to All Craft

These are essentially selected according to the mission requirements. They are:

$V_{K_{max}}$	Maximum speed, knots
V_{K_d}	Design speed (speed at which maximum propulsive coefficient is desired), knots*
V_{K_e}	Endurance speed (speed corresponding to range specification), knots
R	Range, miles
N_C	Number of accommodations
D_s	Dry stores duration, days
$W_{P/L}$	Payload weight, tons. (In general this should be a specification resulting from mission requirements, in which case Equation [28] becomes an implicit equation in gross weight, Δ which can only be solved by iteration. For purposes herein we chose to specify Δ and compute $W_{P/L}$ for ease in computation.)

*Two values are required for this specification if the endurance speed specification is less than hump or take-off speed.

SES Design Parameters

The following parameters are required for determining characteristics of SES:

Symbol	Specification	Units	Procedure for Determining
Δ	gross weight	tons	specify
ℓ/b	cushion length to beam ratio	non-dim	specify
P_o/ℓ	design pressure to length ratio	non-dim	$P_o/\ell = 2/\sqrt{\ell/b}$
$F^2_{\ell_{max}}$	square of maximum Froude no.	non-dim	$F^2_{\ell_{max}} = \dfrac{.00678(P_o/\ell)^{1/3} V_{K_{max}}^2}{\Delta^{1/3}(\ell/b)^{1/3}}$
ℓ	cushion length	feet	$\ell = .08854(V_{K_{max}}/F_{\ell_{max}})^2$
P_o	design cushion pressure	lbs/ft^2	$P_o = (P_o/\ell) \cdot \ell$
α	ratio of V_{K_d} to $V_{K_{max}}$*	non-dim	specify
K_d	waterjet system loss coefficient*	non-dim	specify
$\eta_{P_{max}}$	maximum pump efficiency*	non-dim	specify

With the above now known, Equations [6] through [13] are used to determine the drag/weight ratio at any desired Froude number; $0 < F_\ell \leq F_{\ell_{max}}$. Next corresponding magnitudes of $V_K/V_{K_{max}}$ are determined via

$$\frac{V_K}{V_{K_{max}}} = \frac{\sqrt{g\ell} \cdot F_\ell}{1.6878 V_{K_{max}}}$$

and then Equations [14] through [16] are used to determine the smooth water shaft horsepower required at each speed, $0 < V_K \leq V_{K_{max}}$. The magnitudes of the component weight groups are then found using Equations [21] through [27]. The payload weight then follows from Equation [28]. If the payload weight is insufficient, then the procedure should be repeated using a new gross weight.

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*If secondary propulsion system is assumed, then two values may be required.

Hydrofoil Design Parameters

The following parameters are required for determining the characteristics of hydrofoils:

Symbol	Specification	Units	Procedure for Determining
Δ	gross weight	tons	specify
β	ratio of V_{K_t} to $V_{K_{max}}$	non-dim	specify ($V_{K_t} \leq 35$)
P_{sf}	design foil loading	lbs/ft^2	recommend $P_{sf} = \begin{cases} 1200 \text{ if } 0 < V_{K_{max}} \leq 55 \\ 1600 \text{ if } 55 < V_{K_{max}} < 70 \\ 2100 \text{ if } 70 \leq V_{K_{max}} \leq 100 \end{cases}$
α	ratio of V_{K_d} to $V_{K_{max}}$*	non-dim	specify
K_d	waterjet system loss coefficient*	non-dim	specify
$\eta_{p_{max}}$	maximum pump efficiency*	non-dim	specify

If $0 < V_{K_{max}} \leq 55$, then subcavitating lift systems should be assumed and L/D estimates for the desired speeds, $0 < V_K \leq 55$ may be computed using Equation [17]. For these cases, it is recommended that $\beta = .5$, i.e., assume that the take-off speed is 1/2 of maximum speed.

If $V_{K_{max}} > 55$, then Equation [18] should be used to reflect the lower L/D's obtained with supercavitating lift systems. If $V_{K_{max}} < 70$, then take-off speed may be assumed to be 1/2 of maximum speed, i.e., $\beta = .5$; however, for $V_{K_{max}} \geq 70$, one should select $V_{K_t} = 35$ and determine the appropriate value for β.

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*If secondary propulsion system is assumed, then two values may be required.

Smooth water shaft horsepower magnitudes for each V_K are given by Equation [19], and the payload weight is determined by use of Equations [21] through [28].

Planing Craft Design Parameters

The parameters needed for determining the characteristics of planing craft are:

Symbol	Specification	Units	Procedure for Determining
Δ	gross weight	tons	specify
L_P/B_{PX}	length-beam ratio	non-dim	specify
L_P	projected chine length	ft.	specify
B_{PX}	maximum beam at chine	ft.	specify
$A_P/(35\Delta)^{2/3}$	bottom loading coefficient	non-dim	specify
β_d	deadrise angle	degrees	12.5
α	ratio of V_{K_d} to $V_{K_{max}}$	non-dim	specify
K_d	waterjet system loss coefficient	non-dim	specify
$\eta_{P_{max}}$	maximum pump efficiency	non-dim	specify

Magnitudes of resistance to weight ratios, D/W should be obtained from reference (7) after having selected an LCG location given therein. The procedure may then be completed by use of Equations [20] through [28].

CHARACTERISTICS OF WATERJET PROPELLED HIGH PERFORMANCE VEHICLES

Vehicle concepts considered for purposes of providing a reference vehicle for the selection of specifications for a developmental waterjet propulsion system are categorized according to a desired maximum smooth water speed capability as follows:

$V_{K_{max}}$	Vehicle Concept
50	Planing Craft Hydrofoil SES
75	Hydrofoil SES
100	SES

Design parameters and primary characteristics for the planing craft concepts are shown in Table 1. The selected design parameters have previously been defined. Two particular sets of design specifications, both of which require 50 knot maximum smooth water speed capability, are selected. One is for a vehicle concept having a 50 knot design speed V_{K_d} and a 500-mile range R at that speed V_{K_e}; while the other reflects a concept designed to be most efficient at 25 knots and to have a 500-mile range at 25 knots. For this patrol mission, however, only one propulsion system is assumed. In each case, the number of accommodations N_c and the dry stores duration D_s are assumed to be 12 and 7, respectively.

For each set, gross weights Δ of 50, 100, 150, and 200 tons are selected. For reference, the planing craft PTF has a gross weight of approximately 85 tons and the displacement ship PG has a gross weight of about 225 tons. The geometry selected is the same for both sets. The loss coefficient K_d specified for each set is .5, which is assumed to be representative of waterjet systems having flush (or semi-flush) inlets. Maximum pump efficiencies $\eta_{P_{max}}$ of 90% are assumed. The

TABLE 1 - 50 KNOT PLANING CRAFT CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS

	1	2	3	4	5	6	7	8
$V_{K_{max}}$	50	50	50	50	50	50	50	50
V_{K_d}	50	50	50	50	25	25	25	25
V_{K_e}	50	50	50	50	25	25	25	25
R	500	500	500	500	500	500	500	500
N_C	12	12	12	12	12	12	12	12
D_S	7	7	7	7	7	7	7	7
Δ	50	100	150	200	50	100	150	200
L_p/B_{PX}	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
L_p	68	85	98	108	68	85	98	108
B_{PX}	12.4	15.4	17.8	19.6	12.4	15.4	17.8	19.6
$A_p/(35\Delta)^{2/3}$	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
β_d	12.5	12.5	12.5	[illegible]	12.5	12.5	12.5	12.5
α	1	1	1	1	1	1	1	1
K_d	.5	.5	.5	.5	.5	.5	.5	.5
$\eta_{P_{max}}$	.9	.9	.9	.9	.9	.9	.9	.9

TABLE 1 - 50 KNOT PLANING CRAFT CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS (CONT.)

	1	2	3	4	5	6	7	8
$P(V_{K_d})$	4400	8602	12,708	16,943	2468	4560	6700	8744
$P(V_{K_{max}})$	4400	8602	12,708	16,943	4400	8602	12708	16943
P_{SH}	5060	9892	14,614	19,485	5060	9892	14614	19485
W_S	14.5	27.1	39.2	51.1	14.5	27.1	39.2	51.1
W_{S_1}	0	0	0	0	0	0	0	0
W_m	6.7	13.4	20.0	30.0	6.7	15.0	21.4	30.0
W_e	1.5	3.0	4.5	6.0	1.5	3.0	4.5	6.0
W_{aux}	5.0	10.0	15.0	20.0	5.0	10.0	15.0	20.0
W_{ces}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
W_f	10.5	20.6	29.0	37.1	12.4	19.6	27.5	38.0
$W_{P/L}$	9.3	23.4	39.8	53.3	7.3	22.8	39.9	52.4
No. & Model of Gas Turbines	2 TF25A	4 TF25A	4 501-K14	4 GTPF-990	2 TF25A	2 GTPF-990	2 501-M62	4 GTPF-990
P_{MI}	5000	10000	14,920	22400*	5000	11200*	16000	22400*
P_{MC}	4400	8800	13,600	20000	4400	10000	14000	20000

*at 100°F

resultant overall propulsive coefficient η at maximum speed is .527, while at 25 knots it is .365.

The estimated characteristics, powering and weights, are presented next. The shaft horsepower required by the pump is given at two speeds, i.e., $P(V_{K_d})$ and $P(V_{K_{max}})$. The magnitude of P_{SH} is also given.

The number and model of possible gas turbine installations along with the total maximum intermittent P_{MI} and maximum continuous P_{MC} power rating (at 80°F unless otherwise noted) are shown for each concept.

Tables 2 and 3 present selected design parameters and resultant characteristics for the 50 and 75 knot hydrofoil concepts, respectively. In each case, two "mission profiles" are assumed; the first specifies that $V_{K_d} = V_{K_{max}}$ and that the range at $V_{K_e} = V_{K_{max}}$ be 500 miles, while the second represents a hull-borne cruise capability of 2750 miles for the 50 knot hydrofoils (2000 miles for the 75 knot hydrofoils) at $V_{K_d} = .2V_{K_{max}} = V_{K_e}$ with a dash capability of $V_{K_{max}}$. For this patrol mission, a secondary propulsion system is assumed.* Parameter values characterizing it are given in parentheses next to the selected parameters for the primary propulsion system. For all cases, the number of accommodations N_c and the dry store duration D_s are taken to be 12 and 7, respectively.

For each set, gross weights Δ of 50, 100, 150, and 200 tons are selected. The PGH-2 has a gross weight of 58 tons and the PHM is approximately 224 tons gross weight. The design loading P_{sf} selected for the 50 knot subcavitating hydrofoil concepts is 1200 psf, while for the 75 knot supercavitating hydrofoil concepts it is 2100 psf. The loss coefficient K_d, taken to be .75 for the primary waterjet system, is

*A small diesel installation is assumed but not identified.

TABLE 2 - 50 KNOT HYDROFOIL CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS

	1	2	3	4	5	6	7	8
$V_{K_{max}}$	50	50	50	50	50	50	50	50
V_{K_d}	50	50	50	50	10	10	10	10
V_{K_e}	50	50	50	50	10	10	10	10
R	500	500	500	500	2750	2750	2750	2750
N_c	12	12	12	12	12	12	12	12
D_S	7	7	7	7	7	7	7	7
Δ	50	100	150	200	50	100	150	200
β	.5	.5	.5	.5	.5	.5	.5	.5
P_{sf}	1200	1200	1200	1200	1200	1200	1200	1200
α	1	1	1	1	1 (.2)	1 (.2)	1 (.2)	1 (.2)
K_d	.75	.75	.75	.75	.75 (.5)	.75 (.5)	.75 (.5)	.75 (.5)
$\eta_{p_{max}}$	.9	.9	.9	.9	.9 (.9)	.9 (.9)	.9 (.9)	.9 (.9)

TABLE 2 - 50 KNOT HYDROFOIL CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS, CON'T

	1	2	3	4	5	6	7	8
$P(V_{K_t})$	3410	6820	10230	13640	3410	6820	10230	13640
$P(V_{K_d})$	3238	6475	9712	12950	135	268	403	536
$P(V_{K_{max}})$	3238	6475	9712	12950	3238	6475	9712	12950
P_{SH}	3724	7446	11169	14893	3724	7446	11169	14893
W_S	11.4	21.3	30.8	40.2	11.4	21.3	30.8	40.2
W_{S_1}	6.3	14.9	25.1	36.5	6.3	14.9	25.1	36.5
W_m	5.0	10.0	15.0	20.0	5.8	11.7	17.5	23.3
W_e	1.5	3.0	4.5	6.0	1.5	3.0	4.5	6.0
W_{aux}	5.0	10.0	15.0	20.0	5.0	10.0	15.0	20.0
W_{ces}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
W_f	7.6	15.1	21.4	30.1	6.2	12.3	18.5	24.7
$W_{P/L}$	10.7	23.2	35.7	44.7	11.3	24.3	36.1	46.8
No. & Model of Gas Turbines	1 501-K14	2 501-K14	2 GTPF-990	4 501-K14	1 501-K14	2 501-K14	2 GTPF-990	4 501-K14
P_{MI}	3730	7460	11200*	14920	3730	7460	11200*	14920
P_{MC}	3400	6800	10000	13600	3400	6800	10000	13600

*at 100°F

TABLE 3 - 75 KNOT HYDROFOIL CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS

	1	2	3	4	5	6	.	8
$V_{K_{max}}$	75	75	75	75	75	75	75	75
V_{K_d}	75	75	75	75	15	15	15	15
V_{K_e}	75	75	75	75	15	15	15	15
R	500	500	500	500	2000	2000	2000	2000
N_c	12	12	12	12	12	12	12	12
D_S	7	7	7	7	7	7	7	7
Δ	50	100	150	200	50	100	150	200
β	.4667	.4667	.4667	.4667	.4667	.4667	.4667	.4667
P_{sf}	2100	2100	2100	2100	2100	2100	2100	2100
α	1	1	1	1	1 (.2)	1 (.2)	1 (.2)	1 (.2)
K_d	.75	.75	.75	.75	.75 (.5)	.75 (.5)	.75 (.5)	.75 (.5)
$\eta_{P_{max}}$	.9	.9	.9	.9	.9 (.9)	.9 (.9)	.9 (.9)	.9 (.9)

TABLE 3 - 75 KNOT HYDROFOIL CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS, CON'T

	1	2	3	4	5	6	7	8
$P(V_{K_t})$	7902	15803	23705	31606	7902	15803	23705	31606
$P(V_{K_d})$	7288	14575	21862	29149	359	716	1075	1434
$P(V_{K_{max}})$	7288	14575	21862	29149	7288	14575	21862	29149
P_{SH}	8381	16761	25141	33521	8381	16761	25141	33521
W_S	11.4	21.3	30.8	40.2	11.4	21.3	30.8	40.2
W_{S_1}	4.1	10.0	17.0	25.0	4.1	10.0	17.0	25.0
W_m	12.7	22.5	34.3	45.0	14.8	26.2	40.[illegible]	52.5
W_e	1.5	3.0	4.5	6.0	1.5	3.0	4.5	6.0
W_{aux}	5.0	10.0	15.0	20.0	5.0	10.0	15.0	20.0
W_{ces}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
W_f	11.3	20.6	25.2	41.2	7.9	15.7	23.6	31.4
$W_{P/L}$	1.5	10.1	20.7	20.1	2.8	11.3	16.6	22.4
No. & Model of Gas Turbines	3 TF 35	3 GTPF-990	1 LM 2500	6 GTPF-990	3 TF 35	3 GTPF-990	1 LM2500	6 GTPF-990
P_{MI}	9450	16800*	25600	33600*	9450	16800*	25600	33600*
P_{MC}	8250	15000	24050	30000	8250	15000	24050	30000

*at 100°F

assumed to be representative of waterjet systems having hydrofoil strut/pod ram-type inlets. For the secondary system, assumed to be of the flush type, K_d is taken to be .5. Both primary and secondary systems are assumed to have a maximum pump efficiency of 90%. This leads to an overall propulsive coefficient of .482 at maximum speed, and an overall propulsive coefficient of .527 at the hullborne endurance speed.

The estimated characteristics include, in addition to those presented in Table 1, the shaft horsepower required by the pump at take-off speed, $P(V_{K_t})$.

Design parameters and resultant characteristics for the 50, 75, and 100 knot SES ship concepts are shown in Tables 4, 5, and 6, respectively. For the "transport" mission, i.e., $V_{K_d} = V_{K_{max}} = V_{K_e}$, a range of 500 miles at V_{K_e} is selected. For the "patrol mission" the endurance requirements are specified as 2500 miles at 12 knots for the 50 knot SES concepts and 1500 miles at 18 knots for the 75 and 100 knot SES concepts and a secondary propulsion system is assumed.* For all cases, the number of accommodations N_c and the dry stores duration D_s are assumed to be 12 and 7, respectively.

The gross weights considered for all SES concepts are again taken as 50, 100, 150, and 200 tons. Cushion length-beam, ℓ/b, ratios for the SES transport concepts are selected to be 2. However, for the SES patrol concepts, the ℓ/b is selected to be 4 except for the 100 knot, 200 ton concept. The loss coefficient K_d is taken to be .5 for both propulsion systems and the maximum pump efficiency $\eta_{P_{max}}$ for both systems is assumed to be .9. This gives an overall propulsive coefficient at maximum speed of .527, which may be somewhat optimistic. At the pre-hump endurance speeds, the overall propulsive coefficient is also .527.

*A small diesel installation is assumed, but not identified.

TABLE 4 - 50 KNOT SES CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS

	1	2	3	4	5	6	7	8
$V_{K_{max}}$	50	50	50	50	50	50	50	50
V_{K_d}	50	50	50	50	12	12	12	12
V_{K_e}	50	50	50	50	12	12	12	12
R	500	500	500	500	2500	2500	2500	2500
N_c	12	12	12	12	12	12	12	12
D_s	7	7	7	7	7	7	7	7
Δ	50	100	150	200	50	100	150	200
ℓ/b	2	2	2	2	4	4	4	4
P_o/ℓ	1.414	1.414	1.414	1.414	1.0	1.0	1.0	1.0
$F_{\ell_{max}}$	2.02	1.80	1.68	1.61	1.70	1.52	1.42	1.35
ℓ	54.1	68.2	78.0	85.9	76.5	96.4	110.4	121.5
P_e	77	96	110	121	76	96	110	121
α	1	1	1	1	1 (.24)	1 (.24)	1 (.24)	1 (.24)
K_d	.5	.5	.5	.5	.5 (.5)	.5 (.5)	.5 (.5)	.5 (.5)
$\eta_{P_{max}}$	.9	.9	.9	.9	.9 (.9)	.9 (.9)	.9 (.9)	.9 (.9)

TABLE 4 - 50 KNOT SES CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS, CON'T.

	1	2	3	4	5	6	7	8
$P(V_{K_H})$	1550	3092	4639	6190	1073	2156	3255	4367
$P(V_{K_d})$	2028	3529	4956	6355	145	149	195	236
$P(V_{K_{max}})$	2028	3529	4956	6355	2224	3939	5572	7166
P_{SH}	2332	4058	5699	7308	2558	4530	6408	8241
W_S	21.4	38.1	53.8	68.8	23.0	40.4	56.6	72.0
W_{S_1}	2.5	5.0	7.5	10.0	2.5	5.0	7.5	10.0
W_m	3.3	6.7	8.4	10.0	4.8	7.8	11.7	17.5
W_e	1.5	3.0	4.5	6.0	1.5	3.0	4.5	6.0
W_{aux}	5.0	10.0	15.0	20.0	5.0	10.0	15.0	20.0
W_{ces}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
W_f	5.7	9.3	12.5	15.5	5.1	5.4	7.1	8.6
$W_{P/L}$	8.1	25.4	45.8	67.2	5.6	25.9	45.1	63.4
No. & Model of Gas Turbines	2 7LM100PJ102	2 TF 25A	2 TF 35	2 501-K14	2 TF 14B	2 TF 25A	2 501-K14	2 GTPF-990
P_{MI}	2440	5000	6300	7460	3100	5000	7460	11200*
P_{MC}	2300	4400	5500	6800	2750	4400	6800	10000

*At 100°F

TABLE 5 - 75 KNOT SES CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS

	1	2	3	4	5	6	7	8
$V_{K_{max}}$	75	75	75	75	75	75	75	75
V_{K_d}	75	75	75	75	18	18	18	18
V_{K_e}	75	75	75	75	18	18	18	18
R	500	500	500	500	1500	1500	1500	1500
N_c	12	12	12	12	12	12	12	12
D_s	7	7		7	7	7	7	7
Δ	50	100	150	200	50	100	150	200
ℓ/b	2	2	2	2	4	4	4	4
P_o/ℓ	1.414	1.414	1.414	1.414	1	1	1	1
$F_{\ell_{max}}$	3.93	2.70	2.53	2.41	2.55	2.27	2.12	2.02
ℓ	54.1	68.2	78.0	85.9	76.5	96.4	110.4	121.5
P_e	77	96	110	121	77	96	110	121
α	1	1	1	1	1 (.24)	1 (.24)	1 (.24)	1 (.24)
K_d	.5	.5	.5	.5	.5 (.5)	.5 (.5)	.5 (.5)	.5 (.5)
$\eta_{P_{max}}$	.9	.9	.9	.9	9 (.9)	.9 (.9)	.9 (.9)	.9 (.9)

TABLE 5 - 75 KNOT SES CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS, CON'T

	1	2	3	4	5	6	7	8
$P(V_{K_H})$	2349	4659	6959	9254	1581	3130	4674	6217
$P(V_{K_d})$	5408	8776	11730	14466	379	551	838	1262
$P(V_{K_{max}})$	5408	8776	11730	14466	5444	9015	12205	15195
P_{SH}	6219	10092	13490	16636	6261	10367	14036	17474
W_S	21.4	38.1	53.8	68.8	23.0	40.4	56.6	72.0
W_{S_1}	2.5	5.0	7.5	10.0	2.5	5.0	7.5	10.0
W_m	8.4	15.0	21.4	22.5	9.8	17.5	25.0	37.5
W_e	1.5	3.0	4.5	6.0	1.5	3.0	4.5	6.0
W_{aux}	5.0	10.0	15.0	20.0	5.0	10.0	15.0	20.0
W_{ces}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
W_f	8.5	13.2	17.0	21.7	5.3	7.9	12.0	17.9
$W_{P/L}$	0.2	13.2	28.3	48.5	0.4	13.7	26.9	34.1
No. & Model of Gas Turbines	2 TF 35	2 GTPF-990	2 501-M62	3 GTPF-990	2 TF 35	2 GTPF-990	2 501-M62	3 501-M62
P_{MI}	6300	11200*	16000	16800*	6300	11200*	16000	24000
P_{MC}	5500	10000	14000	15000	5500	10000	14000	21000

*At 100°F

TABLE 6 - 100 KNOT SES CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS

	1	2	3	4	5	6	7	8
$V_{K_{max}}$	100	100	100	100	100	100	100	100
V_{K_d}	100	100	100	100	18	18	18	18
V_{K_e}	100	100	100	100	18	18	18	18
R	500	500	500	500	1500	1500	1500	1500
N_c	12	12	12	12	12	12	12	12
D_s	7	7	7	7	7	7	7	7
Δ	50	100	150	200	50	100	150	200
ℓ/b	2	2	2	2	4	4	4	6
P_o/ℓ	1.414	1.414	1.414	1.414	1	1	1	.816
$F_{\ell_{max}}$	4.05	3.60	3.37	3.21	3.40	3.03	2.83	2.44
ℓ	54.1	68.2	78.0	85.9	76.5	96.4	110.4	148.8
P_e	77	96	110	121	77	96	110	121
α	1	1	1	1	1 (.18)	1 (.18)	1 (.18)	1 (.18)
K_d	.5	.5	.5	.5	.5 (.5)	.5 (.5)	.5 (.5)	.5 (.5)
$\eta_{P_{max}}$	.9	.9	.9	.9	.9 (.9)	.9 (.9)	.9 (.9)	.9 (.9)

TABLE 6 - 100 KNOT SES CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS,CON'T

	1	2	3	4	5	6	7	8
$P(V_{k_H})$	3173	6288	9383	12466	2121	4180	6221	8781
$P(V_{K_d})$	11839	18808	24740	30107	379	551	838	793
$P(V_{K_{max}})$	11839	18808	24740	30107	11347	18275	24265	32109
P_{SH}	13615	21629	28451	34623	13049	21016	27905	36925
W_S	21.4	38.1	53.8	68.8	23.0	40.4	56.6	74.4
W_{S_1}	2.5	5.0	7.5	10.0	2.5	5.0	7.5	10.0
W_m	21.4	32.1	40.2	60.3	25.0	37.5	46.9	70.3
W_e	1.5	3.0	4.5	6.0	1.5	3.0	4.5	6.0
W_{aux}	5.0	10.0	15.0	20.0	5.0	10.0	15.0	20.0
W_{ces}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
W_f	11.9	19.3	23.5	29.6	5.3	7.9	12.0	11.5
$W_{P/L}$	-16.2	-10.1	3.0	2.8	-14.8	-6.3	5.0	5.3
No. & Model of Gas Turbines	2 501-M62	3 501-M62	2 912-C1	3 912-C1	2 501-M62	3 501-M62	2 912-C1	3 912-C1
P_{MI}	16000	24000	30000	45000	16000	24000	30000	45000
P_{MC}	14000	21000	26000	39000	14000	21000	26000	39000

The estimated characteristics presented in Tables 4, 5, and 6 are the same as those given in Table 1, except that the shaft horsepower required by the pump at primary hump speed $P(V_{K_H})$ is also included.

RECOMMENDED VEHICLE CONCEPTS

For each of the 3 maximum smooth water speeds considered - 50, 75, and 100 knots - and for each of the 2 mission type profiles considered - transport and patrol - a vehicle concept is recommended for use as reference craft for waterjet propulsion systems. They are described below.

50 Knot Vehicle Concepts

The payload weight characteristics for all the 50 knot vehicle concepts, given in Tables 1, 2, and 4 are considered acceptable. In fact, the payload weight fractions $(W_{P/L}/\Delta)$ for all these concepts are between .08 and .34. Since the transport mission requires a continuous sustained speed of 50 knots, the hydrofoil concept is recommended for this mission profile as its performance in a seaway is superior to the other two type concepts. However, for the patrol mission profile, the planing craft concept is recommended as it will be cruising at a moderate speed (25 knots or less) most of the time. Moreover, it represents the least complex concept in terms of vehicle technology and cost. Table 7 presents the recommended vehicle concepts.

75 Knot Vehicle Concepts

The 75 knot hydrofoil and SES vehicle concepts are presented in Tables 3 and 5. Insufficient payload capability is indicated for the 50 ton transport vehicle concepts and the 50 ton SES patrol concept, i.e., the payload weight is less than 5% of the gross weight. For both missions, the hydrofoil of larger gross weight is again recommended, even though its payload capability appears to be somewhat less than that of the SES. The selections are presented in Table 7.

TABLE 7: RECOMMENDED VEHICLE CONCEPTS FOR WATERJET PROPULSION DEVELOPMENT PROGRAM

$V_{K_{max}}$	50	50	75	75	100	100
Mission Profile	Transport	Patrol	Transport	Patrol	Transport	Patrol
Recommended Concept	Hydrofoil	Planing Craft	Hydrofoil	Hydrofoil	SES	SES
Gross Weight, tons	50–200	50–200	100–200	100–200	> 200	> 200

100 Knot Vehicle Concepts

In this case, the only concept considered was the SES. The characteristics obtained for the 50 and 100 ton SES concepts (Table 6) indicate that these craft would have no fuel or payload capability. Furthermore, the payload weight for the 150 and 200 ton SES concepts is less than 5% of its gross weight. Thus, all of these concepts are considered infeasible. Viable SES concepts for these missions would have to be larger in gross weight. Table 7 presents the recommendations.

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APPENDIX A: Computerized Method for Waterjet Propelled SES Vehicle Concepts

The computer program "RAVSES" utilizes the method derived herein to estimate the overall propulsive coefficient and the drag of an SES vehicle concept over its operating speed range, and preliminary vehicle and component weights. The program operates in either of two modes; one being specification of payload weight; the second being specification of gross vehicle weight. When payload is specified, gross weight is derived by iteration until the specified payload is satisfied. When gross vehicle weight is specified, the payload weight is calculated directly. If the resulting payload is less than 5 percent of the gross weight, the gross weight is increased iteratively until the 5 percent minimum payload is satisfied. The program will also calculate the predicted drag of the vehicle over a specified speed range.

A description of the input to program "RAVSES", a sample output, and a program listing follow. The headings on the output follow the notation used in the derivation of the method.

INPUT FOR "RAVSES"

Card	Columns	Format	FORTRAN Designation	Explanation
1	1-80	A	TITLE	Any identification to be printed at top of each page of output.
2	1-10	F10.0	LOB	Cushion length-to-beam ratio.
	11-20	F10.0	LOBSW	Sidewall length-to-beam ratio.
	21-30	F10.0	WPL	Payload weight, tons. If WPL=0.0 and DELO is non-zero, payload weight is calculated from DELO and other weight requirements.
	31-40	F10.0	DELO	Vehicle gross weight, tons. If DELO=0.0 and WPL is non-zero, gross vehicle weight is calculated from WPL and other weight requirements by an iterative procedure.
	41-50	F10.0	VKMAX	Maximum vehicle speed in smooth water, knots.
	51-60	F10.0	VKD	Vehicle design speed, knots.
	61-70	F10.0	VKE	Vehicle endurance speed, knots.
	71-80	F10.0	R	Vehicle range, miles.
3	1-10	F10.0	NC	Number of accommodations.
	11-20	F10.0	DS	Dry stores duration, days.
	21-30	F10.0	KD	Waterjet system loss coefficient.
	31-40	F10.0	ETAPM	Maximum pump efficiency.
	41-50	F10.0	PLOPP	Lift horsepower-to-propulsive horsepower ratio.
	51-60	F10.0	EPS	Governs accuracy of gross weight calculation when DELO=0.0 is entered. If the difference between the initial gross weight estimate and the calculated gross weight is greater than EPS tons, another iteration is made.

Card	Columns	Format	FORTRAN Designation	Explanation
3 (con't)	61-70	F10.0	SYST	Use 1 for a single gas turbine. Use 2 for a gas turbine primary system plus a secondary system for low speed operation. If the endurance horsepower is greater than 3000, the secondary system is assumed to be gas turbine; otherwise it is assumed to be diesel.
	71-80	F10.0	PRNT	Use 0 if each iteration is not to be printed. Use 1 if each iteration is to be printed.
4	1-5	I5	NVK	Number of speeds through speed range for which drag prediction are to be made. If NVK = 0, omit cards 4 and 5 through T.
5	1-10	F10.0	VK(1)	Speeds in knots for which drag predictions are to be made. Enter up to 8 speeds per card to a maximum of 60 speeds.
.	11-20	F10.0	VK(2)	
.	.	.	.	
.	.	.	.	
T			VK(NVK)	
T+1	1-5	I5	MORE	Use 0 if another case follows. Use -1 if no more imput follows.

50 KNOT SES CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS

RAVENSCROFT METHOD FOR WATERJET PROPELLED SES CONCEPTUAL DESIGN ITERATION 1

VKMAX	VKO	VKE	RANGE	ACCOM.	DRY ST.	L/B	P/L	PO	LENGTH			
50.	12.	12.	2500.	12.	7.	2.	1.414	77.	54.1			
NO. ENG.	MODEL	PMC	PMI	FNF	PVKE	FNMAX	PVKMAX	FNHUMP	PVKH	KD	ETA	ETAPMAX
2	LM100	2300.	2440.	.49	315.	2.02	2028.	.62	1550.	.50	.53	.90
DELO	DELI	WS	WSL	WM	WE	WAUX	WCFS	WF	WPL			
50.	47.	21.4	2.5	3.8	1.5	5.0	2.5	10.5	2.8			

50 KNOT SES CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS

RAVENSCROFT METHOD FOR WATERJET PROPELLED SES CONCEPTUAL DESIGN ITERATION 1

VKMAX	VKO	VKE	RANGE	ACCOM.	DRY ST.	L/B	P/L	PO	LENGTH			
50.	12.	12.	2500.	12.	7.	2.	1.414	77.	54.1			
NO. ENG.	MODEL	PMC	PMI	FNF	PVKE	FNMAX	PVKMAX	FNHUMP	PVKH	KD	ETA	ETAPMAX
2	LM100	2300.	2440.	.49	315.	2.02	2028.	.62	1550.	.50	.53	.90
DELO	DELI	WS	WSL	WM	WE	WAUX	WCFS	WF	WPL			
50.	47.	21.4	2.5	3.8	1.5	5.0	2.5	10.5	2.8			

V(KTS)	DRAG(LBS)	FN	ETA	POWER	DOW	DWOW	DSAOW	DSVOW	DSWOW	DEOW	DSKOW	DAOW
50.00	6.112E+03	2.02	.53	2.028E+03	5.457E-02	1.115E-02	5.711E-03	3.603E-03	2.965E-06	1.108E-02	1.616E-02	6.873E-03
12.00	3.961E+03	.49	.53	3.154E+02	3.537E-02	3.141E-02	1.027E-03	7.100E-04	2.094E-05	6.380E-04	1.130E-03	4.357E-04
12.00	3.961E+03	.49	.53	3.154E+02	3.537E-02	3.141E-02	1.027E-03	7.100E-04	2.094E-05	6.380E-04	1.130E-03	4.357E-04

```
      PROGRAM RAVSES(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION VK(60)
      LOGICAL MET
      REAL KD,L,LOB,LOBSW,NC,NU
      COMMON /DRAG/DAOW,DEOW,DOW,DSAOW,DSKOW,DSVOW,DSWOW,DWOW,W
      COMMON /PHYS/GRAV,NU,PI,RHO,RHOA
      COMMON /PWR/ALFA,ENG,ETA,ETAPM,KD,NOEN,PLOPP,PLOW,PMC,PMI,PPOW,
     *PVKE,PVKH,PVKM
      COMMON /SES/BSW,DS,FRHUMP,FRMAX,L,LOB,LOBSW,NC,PO,POL,R,SYST,
     *TITLE(8),VKD,VKE,VKMAX
      COMMON /WGHT/DELO,DEL1,WAUX,WCES,WE,WF,WM,WPL,WS,WSL
      MAXIT=5
      DOPL=2.0
      GRAV=32.174
      NU=1.2817E-5
      PI=3.14159265358898
      RHO=1.9905
      RHOA=0.00238
      Q1=2.0
      Q2=1.6878*1.6878/GRAV
      Q3=Q2/2240.**(1./3.)
    1 READ (5,500) (TITLE(I),I=1,8)
  500 FORMAT(8A10)
      READ (5,502) LOB,LOBSW,WPL,DELO,VKMAX,VKD,VKE,R,NC,DS,KD,ETAPM,
     *PLOPP,EPS,SYST,PRNT
  502 FORMAT(8F10.0)
      WRITE(6,600)
  600 FORMAT(1H1)
      IF(DELO.LE.0.) MET=.TRUE.
      IF(WPL.LE.0.) MET=.FALSE.
      IF(MET) DELO=WPL*DOPL
      FRHUMP=SQRT(1./PI*PI/180.*LOB*LOB)
      POL=Q1/SQRT(LOB)
      NSTEP=0
    2 NSTEP=NSTEP+1
      W=DELO*2240.
      FRM2=Q3*VKMAX*VKMAX*(POL/DELO/LOB)**(1./3.)
      FRMAX=SQRT(FRM2)
      L=Q2*VKMAX*VKMAX/FRM2
      PO=POL*L
      BSW=L/LOBSW
      Q4=1.6878/SQRT(GRAV*L)
      ALFA=1.0
      IF(SYST.EQ.2.) ALFA=VKD/VKMAX
      CALL RSACV(VKE*Q4,PVKE)
      PMC=PVKE
      IF(FRHUMP.GT.VKD*Q4) ALFA=1.0
      IF(FRHUMP.LT.FRMAX) CALL RSACV(FRHUMP,PVKH)
      ALFA=1.0
      CALL RSACV(FRMAX,PVKM)
      IF(FRHUMP.GE.FRMAX) PVKH=PVKM
      PMI=PVKM*1.15
      IF(PVKH.GT.PMI) PMI=PVKH
      CALL ENGINE(ENG,PMI,PMC,NOEN)
      IF(MET) GO TO 3
```

```
      WPL=DELO-DEL1
      IF(NSTEP.EQ.1.OR.PRNT.NE.0.) CALL OUT(1,NSTEP)
      IF(WPL.GE.0.05*DELO) GO TO 4
      DELO=1.15*DEL1-WPL
      IF(NSTEP.LE.MAXIT) WPL=0.0
      IF(NSTEP.GT.MAXIT) 4,2
    3 IF(PRNT.NE.0.) CALL OUT(1,NSTEP)
      IF(ABS(DEL1-DELO).LE.EPS) GO TO 4
      DELO=DEL1
      IF(NSTEP.LE.MAXIT) GO TO 2
    4 CALL OUT(2,NSTEP)
      WRITE(6,602)
  602 FORMAT(1H0,*V(KTS)   DRAG(LBS)     FN       ETA     POWER         DOW
     *    DWOW        DSAOW        DSVOW        DSWOW       DEOW        DSKOW
     *    DAOW*//)
      ALFA=1.0
      CALL RSACV(FRMAX,P)
      CALL LINE (FRMAX,P,L,GRAV,ETA)
      IF(SYST.EQ.2.) ALFA=VKD/VKMAX
      CALL RSACV(VKD*Q4,P)
      CALL LINE (VKD*Q4,P,L,GRAV,ETA)
      CALL RSACV(VKE*Q4,P)
      CALL LINE (VKE*Q4,P,L,GRAV,ETA)
      READ (5,504) NVK
  504 FORMAT(I5)
      IF(NVK) 99,1,5
    5 READ (5,502) (VK(I),I=1,NVK)
      DO 6 I=1,NVK
      FR=VK(I)*Q4
      ALFA=1.0
      IF(SYST.EQ.2..AND.VK(I).LE.VKD) ALFA=VKD/VKMAX
      CALL RSACV(FR,P)
      CALL LINE (FR,P,L,GRAV,ETA)
    6 CONTINUE
      READ (5,504) MORE
      IF(MORE) 99,1,1
   99 STOP
      END
```

```
      SUBROUTINE RSACV(FR,P)
      DIMENSION TABFR(42),TABR(42)
      REAL KD,L,LOB,LOBSW,NC,NU
      COMMON /DRAG/DAOW,DEOW,DOW,DSAOW,DSKOW,DSVOW,DSWOW,DWOW,W
      COMMON /PHYS/GRAV,NU,PI,RHO,RHOA
      COMMON /PWR/ALFA,ENG,ETA,ETAPM,KD,NOEN,PLOPP,PLOW,PMC,PMI,PPOW,
     +PVKE,PVKH,PVKM
      COMMON /SES/BSW,DS,FRHUMP,FRMAX,L,LOB,LOBSW,NC,PO,POL,R,SYST,
     +TITLE(8),VKO,VKE,VKMAX
      DATA TABFR/0.,.1,.15,.2,.225,.25,.27,.28,.29,.3,.31,.319,
     +.325,.33,.34,.35,.36,.373,.38,.39,.4,.425,.45,.5,
     +.55,.6,.65,.675,.7,.75,.8,.85,.9,1.,1.1,1.2,
     +1.3,1.4,1.5,1.6,1.7,1.8/
      DATA TABR/0.,.006,.017,.04,.077,.14,.17,.2,.4,.51,.603,.62,
     +.612,.582,.488,.41,.38,.37,.372,.4,.44,.6,.84,1.22,
     +1.435,1.538,1.588,1.6,1.597,1.578,1.542,1.49,1.44,1.36,1.3,1.252,
     +1.218,1.188,1.162,1.14,1.125,1.111/
      EULER=0.5772156649
      EOEP=(SQRT(1.-KD+2.*(KD+SQRT(KD))/(FR/ALFA/FRMAX)**2)-1.)
     + *(FR/ALFA/FRMAX)**2/(KD+SQRT(KD))
      ETA=EOEP*ETAPM*(1.-SQRT(KD)/(1.+SQRT(KD))*(1.-FR/ALFA/FRMAX)**2)
      IF(FR.GE.0..AND.FR.LT.0.5*FRHUMP)
     1WAVEPAR=16.*LOB*FR*FR/(PI*FRHUMP**4.*(1.+1.6*LOB**.25)**2)
     2*(3.-EULER+ALOG(((1.+1.6*LOB**.25)*FRHUMP)**2/(16.*LOB)))
      IF(FR.GE.0.5*FRHUMP.AND.FR.LE.0.8*LOB**.25*FRHUMP)
     1WAVEPAR=EXP(-SQRT(LOB)*FR**0.25)*SIN(PI*FRHUMP**2 / (2.*FR**2))**2
     2+LOB/(PI*(FR+.8*LOB**.25*FRHUMP)**2)
     3*(3.-EULER+ALOG((FR+.8*LOB**.25*FRHUMP)**2/(4.*LOB)))
      IF(FR.GT.0.8*LOB**.25*FRHUMP)
     1WAVEPAR=EXP(-SQRT(LOB)*FR**0.25)*SIN(PI*FRHUMP**2/(2.*FR**2))**2
     2+LOB/(4.*PI*FR**2) * (3.-EULER + ALOG(FR**2/LOB))
      DWOW=4.*WAVEPAR*POL/RHO/GRAV
      VFS=FR*SQRT(GRAV*L)
      QW=RHO*VFS*VFS/2.
      IF(FR.LT.FRHUMP) HA=PO*(1.-0.8*(FR*FR/FRHUMP/FRHUMP))/RHO/GRAV
      IF(FR.GE.FRHUMP) HA=0.2*PO/RHO/GRAV
      RE=VFS*L/NU
      CF=FRICT(1,RE)
      DSAOW=4.0*QW*CF*L*HA/W
      DSVOW=QW*CF*LOB*DWOW/PO
      Q1=8.0*RHO*GRAV/PI
      IF(FR.LE.1.8) CALL DISCOT(FR,FR,TABFR,TABR,TABR,-120,42,0,R1)
      IF(FR.GT.1.8) R1=6.125*ALOG(FR)/FR/FR
      DSWOW=Q1*R1*BSW*BSW*HA*HA/W/L
      QA=RHOA*VFS*VFS/2.
      DEOW=0.2*QA/LOB/PO
      DSKOW=0.1*CF*QW/PO
      CDA=0.393E-4+0.02*CF
      DAOW=CDA*QW/PO
      DOW=DWOW+DSAOW+DSVOW+DSWOW+DEOW+DSKOW+DAOW
      PPOW=DOW*VFS/ETA/550.
      PLOW=PLOPP*PPOW
      P=(PPOW+PLOW)*W
      RETURN
      END
```

```
      SUBROUTINE ENGINE(ENG,PMI,PMC,N)
      DIMENSION TABENG(3,11),NE(11),NMAX(10),PMCN(11),PMIN(11)
      COMMON /WGHT/DELO,DEL1,WAUX,WCES,WE,WF,WM,WPL,WS,WSL
      DATA TABENG/10H     GNOME,825.,970.,10H     LM100,1150.,1220.,
     ,10H     TF14B,1375.,1550.,10H     TF25A,2200.,2500.,10H     TF35 ,
     ,2750.,3150.,10H   501-K14,3400.,3730.,10H  GTPF-990,5000.,5600.,
     ,10H   501-M62,7000.,8000.,10H    912-C1,13000.,15000.,
     ,10H    LM2500,24050.,25600.,10H    FT9A-2,36000.,42500./
      DATA NMAX/6*(2),3*(3),5/
      DO 1 I=1,11
      NE(I)=ROUND((PMI/TABENG(3,I)+.5),1.)
      IF(NE(I).LT.2) NE(I)=2
      IF(TABENG(2,I)*NE(I).LT.PMC) NE(I)=NE(I)+1
      PMCN(I)=TABENG(2,I)*NE(I)
    1 PMIN(I)=TABENG(3,I)*NE(I)
      IMIN=11
      CALL WEIGHT(NE(11),PMCN(11),PMIN(11))
      DELM=DEL1
      DO 2 I=1,10
      IF(NE(I).GT.NMAX(I)) GO TO 2
      CALL WEIGHT(NE(I),PMCN(I),PMIN(I))
      IF(DEL1.GT.DELM) GO TO 2
      IMIN=I
      DELM=DEL1
    2 CONTINUE
      N=NE(IMIN)
      ENG=TABENG(1,IMIN)
      PMC=TABENG(2,IMIN)*N
      PMI=TABENG(3,IMIN)*N
      CALL WEIGHT(N,PMC,PMI)
      RETURN
      END
```

```
      SUBROUTINE WEIGHT(NE,PMCN,PMIN)
      REAL L,LOB,LOBSW,NC
      COMMON /PWR/ALFA,ENG,ETA,ETAPM,KD,NOEN,PLOPP,PLOW,PMC,PMI,PPOW,
     *PVKE,PVKH,PVKM
      COMMON /SES/BSW,DS,FRHUMP,FRMAX,L,LOB,LOBSW,NC,PU,POL,R,SYST,
     *TITLE(8),VKD,VKE,VKMAX
      COMMON /WGHT/DELO,DEL1,WAUX,WCES,WE,WF,WM,WPL,WS,WSL
      IF(PVKE.GT.3000..OR.SYST.EQ.1.) GO TO 1
      SFC=0.4
      WM=0.001562*PMIN
      GO TO 2
    1 N=ROUND((PVKE/PMCN*NE+.5)+1.)
      PEN=PVKE/N
      SFC=1.9*PEN**(-0.15)
      WM=0.001339*PMIN
    2 WS=DELO/SQRT(POL)*(DELO**(-1./3.)+0.3/LOB**(1./3.))
      WSL=0.05*DELO
      WE=0.03*DELO
      WAUX=0.1*DELO
      WCES=0.1*NC+0.015*NC*DS
      WF=DELO*(1.-EXP(-1.*SFC*R*PVKE/(2240.*DELO*VKE)))
      DEL1=WPL+WS+WSL+WM+WE+WAUX+WCES+WF
      RETURN
      END
```

```
      SUBROUTINE OUT(IPAGE,NSTEP)
      REAL KD,L,LOB,LOBSW,NC
      COMMON /PWR/ALFA,ENG,ETA,ETAPM,KD,NOEN,PLOPP,PLOW,PMC,PMI,PPOW,
     +PVKE,PVKH,PVKM
      COMMON /SES/BSW,DS,FRHUMP,FRMAX,L,LOB,LOBSW,NC,PO,POL,R,SYST,
     +TITLE(8),VKD,VKE,VKMAX
      COMMON /WGHT/DELO,DEL1,WAUX,WCES,WE,WF,WM,WPL,WS,WSL
      GO TO (1,2) IPAGE
    1 WRITE(6,600) (TITLE(I),I=1,8)
  600 FORMAT(////28X,8A10)
      GO TO 3
    2 WRITE(6,602) (TITLE(I),I=1,8)
  602 FORMAT(1H1,27X,8A10)
    3 WRITE(6,604) NSTEP
  604 FORMAT(1H0,25X,*RAVENSCROFT METHOD FOR WATERJET PROPELLED SES CONC
     +EPTUAL DESIGN*,10X,*ITERATION *,I1)
      WRITE(6,606) VKMAX,VKD,VKE,R,NC,DS,LOB,POL,PO,L
  606 FORMAT(1H0,*    VKMAX        VKD        VKE      RANGE      ACCOM.
     +   DRY ST.     L/B       P/L          PO       LENGTH*/1X,7F10.0,F10.3,
     +F10.0,F10.1)
      FRE=VKE*FRMAX/VKMAX
      WRITE(6,608) NOEN,ENG,PMC,PMI,FRE,PVKE,FRMAX,PVKM,FRHUMP
  608 FORMAT(1H0,*   NO. ENG.     MODEL        PMC          PMI          FRE
     +    PVKE      FRMAX     PVKMAX      FRHUMP     PVKH          KD         ETA
     +       ETAPMAX*/I11,A10,2F10.0,3(F10.2,F10.0))
      IF(FRHUMP.LE.FRMAX) WRITE(6,610) PVKH
  610 FORMAT(1H+,90X,F10.0)
      IF(FRHUMP.GT.FRMAX) WRITE(6,612)
  612 FORMAT(1H+,90X,*        ---- *)
      WRITE(6,614) KD,ETA,ETAPM
  614 FORMAT(1H+,100X,3F10.2)
      WRITE(6,616) DELO,DEL1,WS,WSL,WM,WE,WAUX,WCES,WF,WPL
  616 FORMAT(1H0,*        DELO        DEL1         WS          WSL         WM
     +     WE         WAUX        WCES         WF          WPL*/1X,2F10.0,8F10.1)
      RETURN
      END
```

```
      SUBROUTINE LINF(FR,P,L,G,ETA)
      REAL L
      COMMON /DRAG/DAOW,DEOW,DOW,DSAOW,DSKOW,DSVOW,DSWOW,DWOW,W
      VK=FR*SQRT(G*L)/1.6878
      D=DOW*W
      WRITE(6,600) VK,D,FR,ETA,P,DOW,DWOW,DSAOW,DSVOW,DSWOW,DEOW,DSKOW,
     *DAOW
  600 FORMAT(1X,F6.2,1PE11.3,0P2F7.2,1P9E11.3)
      RETURN
      END
```

```
      SUBROUTINE DISCOT (XA,ZA,TABX,TABY,TABZ,NC,NY,NZ,ANS)             DISCOT01
      DIMENSION TABX(10),TABY(1440),TABZ(144),NPX(8),NPY(8),YY(8)
      CALL UNS (NC,IA,IDX,IDZ,IMS)                                      DISCOT03
      IF (NZ-1)   5,5,10                                                DISCOT04
    5 CALL DISSER (XA,TABX,1,NY,IDX,NN)                                 DISCOT05
      NNN=IDX+1                                                         DISCOT06
      CALL LAGRAN (XA,TABX(NN),TABY(NN),NNN,ANS)                        DISCOT07
      GOTO 70                                                           DISCOT08
   10 ZARG=ZA                                                           DISCOT09
      IP1X=IDX+1                                                        DISCOT10
      IP1Z=IDZ+1                                                        DISCOT11
      IF (IA)   15,25,15                                                DISCOT12
   15 IF (ZARG-TABZ(NZ))   25,25,20                                     DISCOT13
   20 ZARG=TABZ(NZ)                                                     DISCOT14
   25 CALL DISSER (ZARG,TABZ,1,NZ,IDZ,NPZ)                              DISCOT15
      NX=NY/NZ                                                          DISCOT16
      NPZL=NPZ+IDZ                                                      DISCOT17
      I=1                                                               DISCOT18
      IF (IMS)   30,30,40                                               DISCOT19
   30 CALL DISSER (XA,TABX,1,NX,IDX,NPX)                                DISCOT20
      DO 35 JJ=NPZ,NPZL                                                 DISCOT21
      NPY(I)=(JJ-1)*NX+NPX(1)                                           DISCOT22
      NPX(I)=NPX(1)                                                     DISCOT23
   35 I=I+1                                                             DISCOT24
      GOTO 50                                                           DISCOT25
   40 DO 45 JJ=NPZ,NPZL                                                 DISCOT26
      IS=(JJ-1)*NX+1                                                    DISCOT27
      CALL DISSER (XA,TABX,IS,NX,IDX,NPX(I))                            DISCOT28
      NPY(I)=NPX(I)                                                     DISCOT29
   45 I=I+1                                                             DISCOT30
   50 DO 55 I=1,IP1Z                                                    DISCOT31
      NLOC=NPX(I)                                                       DISCOT32
      NLOCY=NPY(I)                                                      DISCOT33
   55 CALL LAGRAN (XA,TABX(NLOC),TABY(NLOCY),IP1X,YY(I))                DISCOT34
      CALL LAGRAN (ZARG,TABZ(NPZ),YY,IP1Z,ANS)                          DISCOT35
   70 RETURN                                                            DISCOT36
      END                                                               DISCOT37
```

```
      SUBROUTINE LAGRAN (XA,X,Y,N,ANS)                              DISCOT54
      DIMENSION X(10),Y(1440)
      SUM=0.0                                                       DISCOT56
      DO 3 I=1,N                                                    DISCOT57
      PROD=Y(I)                                                     DISCOT58
      DO 2 J=1,N                                                    DISCOT59
      A=X(I)-X(J)                                                   DISCOT60
      IF (A)   1,2,1                                                DISCOT61
    1 B=(XA-X(J))/A                                                 DISCOT62
      PROD=PROD*B                                                   DISCOT63
    2 CONTINUE                                                      DISCOT64
    3 SUM=SUM+PROD                                                  DISCOT65
      ANS=SUM                                                       DISCOT66
      RETURN                                                        DISCOT67
      END                                                           DISCOT68


      SUBROUTINE DISSER (XA,TAB,I,NX,ID,NPX)                        DISCOT69
      DIMENSION TAB(10)
      NPT=ID+1                                                      DISCOT71
      NPB=NPT/2                                                     DISCOT72
      NPU=NPT-NPB                                                   DISCOT73
      IF (NX-NPT)   10,5,10                                         DISCOT74
    5 NPX=I                                                         DISCOT75
      RETURN                                                        DISCOT76
   10 NLOW=I+NPB                                                    DISCOT77
      NUPP=I+NX-(NPU+1)                                             DISCOT78
      DO 15 II=NLOW,NUPP                                            DISCOT79
      NLOC=II                                                       DISCOT80
      IF (TAB(II)-XA)   15,20,20                                    DISCOT81
   15 CONTINUE                                                      DISCOT82
      NPX=NUPP-NPB+1                                                DISCOT83
      RETURN                                                        DISCOT84
   20 NL=NLOC-NPB                                                   DISCOT85
      NU=NL+ID                                                      DISCOT86
      DO 25 JJ=NL,NU                                                DISCOT87
      NDIS=JJ                                                       DISCOT88
      IF (TAB(JJ)-TAB(JJ+1))   25,30,25                             DISCOT89
   25 CONTINUE                                                      DISCOT90
      NPX=NL                                                        DISCOT91
      RETURN                                                        DISCOT92
   30 IF (TAB(NDIS)-XA)   40,35,35                                  DISCOT93
   35 NPX=NDIS-ID                                                   DISCOT94
      RETURN                                                        DISCOT95
   40 NPX=NDIS+1                                                    DISCOT96
      RETURN                                                        DISCOT97
      END
```

```
      SUBROUTINE UNS (IC,IA,IDX,IDZ,IMS)                                DISCOT38
      IF (IC)   5,5,10                                                  DISCOT39
    5 IMS=1                                                             DISCOT40
      NC=-IC                                                            DISCOT41
      GOTO 15                                                           DISCOT42
   10 IMS=0                                                             DISCOT43
      NC=IC                                                             DISCOT44
   15 IF (NC-100)   20,25,25                                            DISCOT45
   20 IA=0                                                              DISCOT46
      GOTO 30                                                           DISCOT47
   25 IA=1                                                              DISCOT48
      NC=NC-100                                                         DISCOT49
   30 IDX=NC/10                                                         DISCOT50
      IDZ=NC-IDX*10                                                     DISCOT51
      RETURN                                                            DISCOT52
      END                                                               DISCOT53
```

```
      FUNCTION FRICT(IFRICT,RE)                                         FRI  001
      GO TO (4,2) IFRICT                                                FRI  002
    2 FRICT=.075/(ALOG10(RE/100.))**2 $GO TO 99                         FRI  003
    4 X=1./(3.46*ALOG10(RE)-5.6)**2                                     FRI  004
    6 FRICT=(.242/ALOG10(RE*X))**2                                      FRI  005
      IF(ABS(FRICT-X).LT.5.E-07) GO TO 99                               FRI  006
      X=(FRICT+X)/2.                                                    FRI  007
      GO TO 6                                                           FRI  008
   99 RETURN                                                            FRI  009
      END                                                               FRI  010
```

```
      FUNCTION ROUND(X,V)                                               RND  001
C     X IS VARIABLE TO BE ROUNDED                                       RND  002
C     V IS THE VALUE TO WHICH X IS TO BE ROUNDED                        RND  003
      X=X/V $TX=NX=X $DX=X-TX $TDX=NX=2.0*DX $ROUND=(TX+TDX)*V          RND  004
      RETURN                                                            RND  005
      END                                                               RND  006
```